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A Comparison of the Accuracy of Objective Physiological Measuring Techniques for Rigidity in Parkinson's Disease – A Systemic Review

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ABSTRACT

Background and Aim: Parkinson's disease (PD), a common neurodegenerative disorder, often presents with debilitating rigidity. Despite its significance, rigidity assessment is qualitative, subjective and reliant on the examiner's interpretation. This study aimed at comparing the reliability and applicability of objective methods for rigidity assessment in PD patients.

Methods: A systematic search in 4 bibliographic databases. Primary outcome was an objective assessment method of rigidity in PD, where reliability and correlation with UPDRS rigidity were reported. The secondary outcome was applicability of the method in a clinical setting.

Results: The study revealed the following rigidity assessment methods: isokinetic techniques, surface electromyography (sEMG), acoustic myography (AMG), myotonometry, and setup of devices based on force, inertia and mechanomyography sensors (FIM). Among 21 relevant studies, isokinetic techniques, while highly reliable, presented challenges in daily settings. Combining isokinetic assessment with sEMG gave insights into the neurophysiological origins of rigidity. Myotonometry exhibited ease of use and reliability but lacked a sufficiently high correlation with UPDRS rigidity scores. AMG emerged as highly reliable, with strong correlations to UPDRS assessments, and easy interpretation of data. sEMG recordings, while providing insights into muscle activity, posed challenges in signal interpretation. FIM showed promising outcomes with high reliability, applicability and correlation to UPDRS rigidity score.

Conclusion: AMG and FIM appear promising for rigidity assessment in PD. Both methods are easily applicable in the clinic, but only limited number of studies using these methods have been carried out so far.

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Introduction

Parkinson disease (PD) is recognized as one of the most common progressive neurodegenerative diseases. Clinically PD is characterized by bradykinesia, tremor, rigidity and postural instability [1]. Diagnosis of PD is still defined by the evaluation of cardinal motor symptom [2,3].

Rigidity, a cardinal symptom in PD, plays a vital role in clinical diagnosis and serves as a finding playing an important role for the evaluation of treatment effectiveness. Its positive response to dopaminergic medication and surgical intervention is well-documented [4,5]. Parkinsonian rigidity is characterized by increased resistance to passive limb movement, presenting as a constant and uniform resistance across the entire range of motion [6]. The Unified Parkinson's Disease Rating Scale (UPDRS) incorporates a clinical rigidity score, assessing the examiner's perception of resistance during imposed movements of the subject's wrist, elbow, neck, or ankle joints [7,8]. This evaluation is qualitative and subjective, reliant on the examiner's individual interpretations and experience [8]. Subjective bias is therefore considered to be a high risk with these measurements [9]. Indeed, an introduction of an objective means of quantification of rigidity is much needed in the PD clinical setting.

Exploring the underlying physiological mechanisms of rigidity has been the focus of numerous studies. Electromyographic (EMG) studies have contributed valuable insights, indicating that in PD the short-latency stretch reflex remains normal [10,11]. Conversely, the long-latency stretch reflex is reported to be exaggerated in individuals with PD when compared to healthy controls (HC) [10,12,13].

Recent biomechanical studies have unveiled a dependence of rigidity on both the amplitude and velocity of passive movement [14,15]. Additionally, attempts have been made to utilize EMG mean values, as well as ratios, as markers for rigidity, with findings indicating an increase in such parameters in association with rigidity [14].

A recent study using acoustic myography (AMG) has opened a new chapter of possibilities with its method of assessing muscle fibre activity during both passive and active movements. This approach offers a reliable and easily applicable method for evaluation of rigidity in PD patients [16].

The aim of the present study was, through a systematic review, to compare the accuracy and applicability of existing objective methods for rigidity assessment so as to be able to recommend the most reliable and easily applicable objective method for rigidity assessment in PD patients in the neurology clinic.

Methods

The present study has been carried out as a systematic review, and the protocol was registered prior to the start of the study in PROSPERO (https://www.crd.york.ac.uk/prospero/), No. CRD42023430342. Reporting has been undertaken according to the PRISMA statement where applicable [17].

Inclusion Criteria
- Studies on PD patients diagnosed according to UK Parkinson disease Society Brain Bank Criteria [18].
- Muscle rigidity must be defined as a clinical sign (hypertonic state induced by passive movement).
- Assessment of rigidity must be carried out with an objective measuring technique.

Exclusion Criteria
- Patients with secondary Parkinsonism
- Patients with other neurodegenerative disease than PD
- Patients with any condition/disease affecting muscles/joints
- Studies including less than 10 PD patients and/or 10 HC, since we consider such a study to be a pilot study.

Literature Search
The Following Bibliographic Databases were Searched
Medline via Pubmed from 1946, EMBASE via OVID from 1974, Cochrane Database from 1992, and Web of Science from1900, all up to the 18th August 2023. Reference lists from extracted relevant studies and reviews were also checked for further relevant studies.

Search Strategy
(Parkinson`s Disease AND (rigidity OR muscle stiffness) AND assessment) All TI/AB.
The extended search is described in detail in Table 1.

Table 1: Search Strategy

Parkinson*	Rigidity	Assessment *
	Muscle stiffness	Electromyography
	Muscle tonus	EMG
		Acoustic myography
		Ultrasound
		US
		Magnetic Resonance
		MRI
		Dynamometer
		Pressure transducer
		AMG
		sEMG

All Terms were Searched TI/AB.

There were no Language Restrictions
Study Selection
All study types, except for pilot studies, measuring rigidity in PD patients by means of an objective method were included.

Retrieval of Studies
Two authors were involved in the selection process (MC, EMB). If disagreement occurred, a third author was consulted (APH).

Data Extraction
The following data were extracted from the included studies:
- Study type
- Description of clinical data on participants
- Methods for measuring of rigidity
- Rigidity data

Outcomes
Primary Outcome: Accuracy of rigidity measured as reliability and correlation to UPDRS rigidity.
Secondary Outcome: Applicability of measuring technique in the clinic.

Data Handling
Accuracy was defined by reliability of the method and how well the method was correlated to UPDRS rigidity. UPDRS rigidity was chosen for the comparison, since no objective golden standard for rigidity assessment exists, and UPDRS rigidity is the most applied measure for rigidity in PD worldwide at present.

Comparison of the different objective rigidity techniques was pre study start planned to be carried out. The variation in application of a given method, where more studies were available, and the small number of existing studies for some techniques, made a direct statistical comparison of the different rigidity measuring methods impossible.

Results
The total search from Medline, EMBASE, Cochrane and Web of Science resulted in 6748 records prior to removal of duplicates. Following removal of duplicates, a total of 4409 retrieved papers were all studies considered for inclusion. Of those, 222 were included to read in full-text, and 10 relevant reviews were also included for checking of reference lists. These reviews gave no further studies to include. Out of the 222 studies, 21 were finally included for data extraction. Apart from excluding non-relevant studies we also excluded 6 pilot studies and 8 studies which could not be obtained in full-text. The included studies showed that the present objective rigidity measuring methods applied with PD were isokinetic measurements, sEMG, AMG, FIM and myometry. Eight studies applied a combination of these.

The Selection Process is Shown in Figure 1
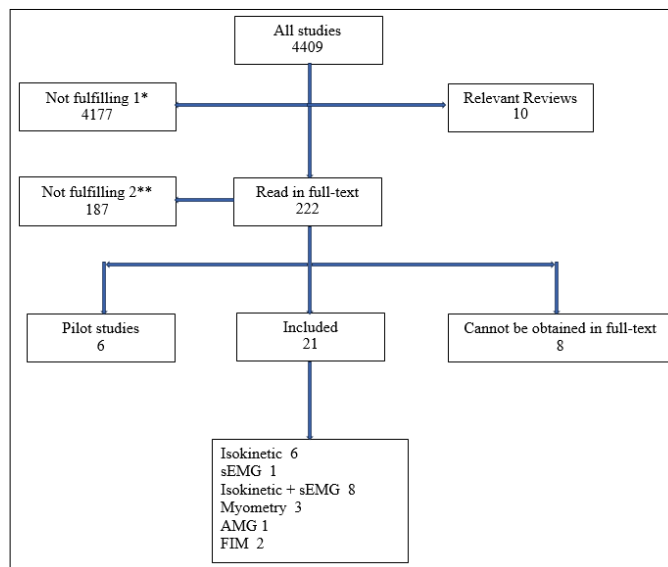
*Selection based on title and abstract
**Selection following reading in full-text
Figure 1: Flowchart of the Selection Process of Studies

The 21 studies included in this systematic review are shown in Table 2.

Table 2: Included studies. As a clinical evaluation of stage of Parkinson disease, Hohn and Yahr (H&Y), given class I-IV, is used in some of the studies. Duration of disease (DofD) is given in studies where data is available. NS stands for non-significant. SD is standard deviation, and r is spearman's correlation coefficient.

2A: Isokinetic Measurements/Techniques

Study	Subjects	Method	Results
Kirollos et al. [19]	20 PD patients matched with 20 HC. No additional clinical data provided	Measurement of hysteresis during isokinetic and isometric elbow joint movement	Reliability of method founded as "good"; r=0,71 CI:95%. Correlation to UPDRS was not measured
Little et al. [20]	12 PD patients No gender data Age = 61,5±1,9 DofD = 13,1±1,6	Isokinetic measurements over wrist in medical "on and "off" state by measuring torque and sEMG	Rigidity significantly increased by 24% within low-frequency stimulation ±20Hz (p=0,035), whereas high frequency stimulation (130Hz) reduced rigidity by 18% (p=0,033).
Kwon et al. [21]	8 PD patients (4m / 4w), 16 wrists had been examined (6 patients bilateral and 2 patients unilateral) Age = 57.1±9.6 H&Y = 2.6±9.6 DofD = 12.1±5.6	Measurements of resistive torque during isokinetic movements over wrist	Viscosity damping constant shown highest significance (p±0.001). Spearman correlation coefficient r=0.51-0.72 for correlation between mechanical and clinical score. Best correlation was shown for viscosity p=0.77±0.22
Cano-de-la-Cuerda et al. [22]	36 PD patients (29m /7w) Age = 62±11 years DofD = 55.4±14.3 months Mean of UPDRS III = 22±8 H&Y = 8 IB, 24 II, 4 III	Isokinetic (Biodex System 3) measurements. Resistive torque was recorded as trunk flexor and extensor's rigidity (W/body weight).	Rigidity was recorded at velocities: 30o/s (r=0.384 p=0.02), 45 o/s (r=0.352 p=0.035), and 60 o/s (r=0.348 p=0.037) in trunk extensors significantly correlates with UPDRS rigidity. p±0.005 for all measurements. No significant correlation with rigidity recorded in trunk flexors

Tan et al. [23]	15 PD patients (12m / 12w) Age = 69±5 DofD = 9±6 UPDRS III = 29±14 15 HC (9m /6w)	Isokinetic measurements of m. gastrocnemius	Stiffness coefficient (m-1) PD 89.3 ± 28.3 HC 77.3 ± 32.4 p=0.19 non-significant difference (NS)
Zetterberg et al. [24]	25 PD (16m / 9w) Age = 72.3±6 DofD = 7.0±5.4 H&Y = 2±1 UPDRS III = 26±14 14 HC age and gender matched	"NeuroFlexor" setup used for isokinetic measurements over wrist in passive and dynamic (during activation maneuver) state. Passive (inertia, viscosity, elasticity) component and active (neural) component of rigidity was calculated	Significantly increased passive stretch resistance in passive and dynamic state compared to HC. Neural component contributed significantly to resistance/rigidity in PD and correlated to UPDRS rigidity in both passive and dynamic state.

Five studies which used isokinetic method for objective measurement of rigidity showed high reliability, while one study showed a lower "good" reliability.

2B: Surface EMG (sEMG)

Study	Subjects	Method	Results
Abbruzzese et al. [25]	40 PD (22m /18w) Clinically akinetic features, tremor dominant patients were excluded Age = 64±7.8 30 HC (18m /12w) Age = 60.9±12	sEMG recordings of abductor policis brevis.	F-wave amplitude and duration was significantly increased in PD patients compared to HC

*This study used surface EMG only as an objective method for assessment of rigidity. sEMG measurements focused here on F-waves, showing a significantly increased amplitude and duration of the F-wave in PD compared to HC.

The studies given in Table 2B have been included because they have importance for the further development of using the sEMG index as a measure for rigidity. The measured parameters are of importance in understanding the components of measured rigidity.

2C: Isokinetic + sEMG

Study	Subjects	Method	Results
Berardelli et al. [26]	17 PD patients No age and gender data DofD = 1-20y No additional clinical data provided	Isokinetic measurements on different angular velocities produced by dorsal flexion stretch of tibialis anterior and triceps surae, all supported by sEMG	The long-latency reflex magnitude and duration increased in PD patients compared to HC
Powell et al. [14]	18 PD patients (7m / 11w) Dominant akinetic clinical features Age = 64±9	Isokinetic torque measurement over wrist joint and sEMG recordings from muscles of the hand and forearm in PD patients in medical "on" and "off" state.	Significantly higher torque-angle slopes (F=22.64, p<0.001) during the "fast" condition (280o/s). Increased EMG ratio and mean of stretched muscles in PD.
Powell et al. [27]	18 PD patients (7m / 11w) Age = 40-80 No additional clinical data provided	Rigidity measured by continuously (CONT) and discontinuously (DISC) movement trajectories by strain gauge torque transducer controlled by servo motor. This method was supported by sEMG which measured stretch reflex response.	There was no difference observed between CONT and DISC movement trajectories (p=0.18) Dopaminergic medication significantly reduced rigidity (p=0.02) and EMG amplitudes in stretched muscles during extension in PD (p<0.05)
Xia et al. [28]	17 PD patients (6m / 11w) Age = 62±8.9 DofD = 0.5 -13 years No additional clinical data provided	Isokinetic measurements over wrist recording the torque and sEMG in both "on" and "off" medical state by strain gauge torque transducer controlled by servo motor. This method was supported by sEMG	Results showed that both shortening reaction (SR) and stretch induced inhibition (SII) contributed to rigidity, (p=0.003)

Xia et al. [29]	14 PD patients (10m / 4w) Age = 62.6±9.1 No additional clinical data provided 14 HC age/gender matched	Isokinetic measurements of wrist and sEMG measurements in medical "on" and "off" state.	Neural reflex contributes significantly to rigidity compared to intrinsic mechanical components, F=6.21; p=0.020 Dopaminergic medication reduced significantly the neural reflex. Non-significant correlation between reflex sEMG and neural torque.
Endo et al. [30]	27 PD patients (16 m / 11 w) Age = 70±7.4 DofD = 1 to 20 24 HC (18 m / 6 w) Age = 67.6±9	Muscle tone measuring by 3-axisis force sensor, gyro sensor and sEMG during passive flexion phase and extension phase over elbow joint by examiner. "sEMG index" recorded and calculated from activity in biceps and triceps brachi as a measure of rigidity	PD sEMG index $\geq$ 1 HC sEMG index $\leq$ 1 Correlation with UPDRS rigidity: sEMG index biceps brachi (r=0.72, 95%CI:0.60-0.81) sEMG index triceps brachi (r=0.37, 95%CI:0.17-0,54) Isokinetic elastic coefficient extension (r=0.65,95%CI:0.51-0.75), flexion (r=0.60,95%CI:0.45-0.72)
Endo et al. [31]	24 PD patients (17 m / 7 w) Age = 69.8±7.6 DofD = 1-20 20 HC (15 m / 5w) Age = 71.2±7.2	Muscle tone measured by 3-axis force sensor, gyro sensor and sEMG during passive flexion and extension phase over elbow joint	Correlation to UPDRS rigidity: Isokinetic elastic coefficient distal flexion (over 60o) (r=0.59,95%CI:0.39-0.79), NS. Significant difference in elastic coefficient for distal extension between group rigidity 0 and 1. Logistic discrimination analysis (elastic coefficient from all measurements, age, gender and side) showed that HC could be differentiated with 78% of sensitivity, 83.3% of specificity and 81.5% correct classification rate
Endo et al. [32]	20 PD patients (10m /10w) Age = 74.4±6.2	Isokinetic measuring over elbow joint by 3-axis force sensor, gyro sensor and sEMG during passive flexion and extension	The elastic coefficient was not velocity-dependent, but the difference in bias increased in a velocity-dependent manner (P = 0.0017).

One of the studies using sEMG in combination with isokinetic measurements {Berardelli, 1983 #6683} found that long-latency stretch reflex had greater magnitude and longer duration in PD patients. Different biomarkers like the sEMG index were used. The sEMG index was found to be significantly increased in PD and well correlated with UPDRS rigidity for m.biceps brachii, but poorly correlated with UPDRS rigidity in m.triceps brachii.

Elastic coefficient, which was significantly velocity dependent together with age, gender and side of PD clinical domination, could differentiate PD patients from HC with a sensitivity of 78%, a specificity of 83% and with 81,5% rate of correct classification {Endo, 2013 #3154}. In general, isokinetic studies together with sEMG showed relatively high reliability but not constant high correlation with the UPDRS rigidity score.

2D: Myometry/Myotonemetry

Study	Subjects	Method	Results
Marusiak et al. [33]	10 PD patients (4m /6w) Age = 68±10 DofD = 9±4 H&Y = 2.5-3 (one 4) UPDRS rigidity median score "off" vs "on" respectively: 2 vs 1	Measurements of rest stiffness in biceps brachii, triceps brachii and brachioradialis by myometry (Myoton-3) supported by sEMG (to ensure that the explored muscle is in rest) in medication "on" and "off" state	High reliability was shown according to interclass correlation coefficient. Significantly lower myometric stiffness and electromyogram amplitude in all tested muscles, and also lower clinical rigidity scores during the medication on-phase compared with the medication off-phase. Statistically significant correlation for measurements of stiffness and sEMG in biceps brachii, (r=0,0424; p=0,031). Non-significant for other measured muscles.
Agoriwo et al. [34]	30 PD patients (19m / 11w) Age = 66.3±8.9 DofD = 2.89±2.18 H&Y = 2.35±0.62	Mechanical properties (Biceps brachii, flexor carpi radialis and tibialis anterior muscles) by MyotonPRO device	Reliability according to Interclass correlation coefficient (ICC 3.2): For biceps brachii ICC±92 (excellent), for Flex.carpi radialis ICC±0.73 (moderate). Pearson's correlation for correlation between UPDRS and Myoton data shown poor positive correlation with UPPDRS and Myoton data for stiffness. (r=0.47, p=0.018)
de la Cruz et al. [35]	33 PD (18 in intervention group and 15 in control group of PD patients) Age = 69±7.2	Double blind randomized clinical trial for "deep needling" procedure as type of acupuncture. Among other parameters mytonometry by MyotonPRO was measured before and after intervention.	A single session of dry needling had no measurable benefits. Myotonometry used for assessment of rigidity where ANOVAs showed significant effects of time for stiffness (F = 4.92; p = 0.013) while the control group remained invariable

Rigidity measured by myotometry is a reliable method, but the correlation to UPDRS is poor.

2E: Acoustic Myography (AMG)

Study	Subjects	Method	Results
Celicanin et al. [16]	20 PD patients (13m /7w) Age = 68.5±7.3 D0fD = 5.3±2.3 median H&Y stage 2 20 age and gender UPDRS III in "off" – 16.1±6.5, and in "on" – 9.4±4.5 matched healthy subjects	AMG activity recorded during active and passive movements over elbow and wrist joint in medication "on" and "off" state Rigidity was assessed as the S:T score	Biceps brachii: passive E-score 0.91±1.21(SD) Active E-score 0.41±0,46(SD) Passive S-score 3.74±3.3 Ext.carpi radialis: Passive E-score 0.58±0.73 (SD) S-score 4.94±2.23 (SD) Active S-score 2.48±2,16 (SD) Triceps brachii NS results for all measurements S:T ratio significantly lower in PD compared to HC

In the only AMG study on PD, the S:T score correlates well with UPDRS rigidity. The reliability of the method is good {Celicanin, 2023 #15}.

2F: FIM			
Study	**Subjects**	**Method**	**Results**
Lopes et al. [36]	10 PD patients with bilateral STN-DBS* surgeries No additional clinical data provided	"IHandU" device Wrist rigidity measured by inertial and force sensors supported by gyroscope controlled via software developed for this purpose. Measurements performed before and after deep brain stimulation.	This method showed an accuracy 78% and a mean error of (3.6±4%) according to UPDRS assessment.
Huo et al. [37]	23 PD patients (12 m / 11 w) Age = 37-73 years H&Y = 1-5 10 HC (8m / 2w) Age = 27.6±3	Rigidity assessment by examiner during UPDRS scoring and simultaneous recording of mechanomyography (MMG) sensors, which contains 3d accelerometer, 3d gyroscope and 3d magnetoscope and force/ inertia sensors measuring torque during "on" and "off" DBS stimulation	Wrist rigidity measurement showed 88.4% correlation with UPDRS rigidity assessment, and 89.4% correlation for rigidity over the elbow joint with UPDRS

*Subthalamic nucleus – deep brain stimulation
FIM showed high accuracy and high correlation with UPDRS rigidity score.

Discussion

The primary objective of this study was to conduct a comparative analysis of the accuracy and applicability of existing objective methods for rigidity assessment in Parkinson's disease patients. The goal was to provide recommendations for the adoption of the most precise and readily applicable objective method for rigidity assessment in this patient population.

By undertaking this investigation, we tried to contribute insights into the comparative effectiveness of established objective techniques for evaluating rigidity in PD.

Looking at accuracy, we assessed the reliability of each of the existing objective rigidity measuring methods. The other part of the assessment was the practical applicability of the method in a clinical setting.

While acknowledging that UPDRS has some subjective bias, we used it as our "Golden standard" due to its widespread utilization in nearly all Neurology clinics today, since no objective "Golden standard" method for rigidity exists for PD [8,9,38,39].

Our searches revealed that the following objective methods had been used for rigidity measurements in PD: isokinetic measurements, surface electromyography (sEMG), acoustic myography (AMG), myotonometry, a setup of force, inertia and mechanomyography sensors (FIM), as well as combinations of isokinetic measurements and sEMG [16,21,22,25,26,30,31,33,34,36,37]. Two of the rigidity measuring techniques, isokinetic and sEMG measurements, had enough studies to carry out a meta-analysis to strengthen the data except that the measuring setups and the muscles measured varied to a degree which made such an analysis meaningless.

The isokinetic measuring techniques, while highly reliable, showed challenges in daily settings. First, it demands trained staff and time-consuming analysis of data, and there is a variety in available devices, and in how different laboratories use these setups. Another problem is that these setups often have a substantial physical size, making use of these difficult in the space available in the general clinic [21,22,27,36,40]. Isokinetic rigidity measurements are shown to correlate well with UPDRS [24].

Isokinetic assessment coupled with surface electromyography (sEMG) has been an area of investigation for many years [26,30]. The primary objective of these studies was to define rigidity as a phenomenon from a neurophysiological perspective [26]. In one study it was observed that the long-latency stretch reflex exhibited greater magnitude and prolonged duration, alongside a lengthened shortening reaction [26]. This finding suggested a potential central nervous system origin of PD rigidity. It is noteworthy that these investigations did not explicitly aim at establishing a correlation between sEMG and the clinical assessment of rigidity for practical everyday clinical use. Nonetheless, the authors expressed an interest in identifying a specific parameter associated with rigidity, one that could potentially correlate with the UPDRS. In the exploration of various parameters, the utilization of the sEMG index has been a focal point [14,31,33]. The sEMG index showed a significant increase in PD and correlated with UPDRS rigidity in the m. biceps brachii. Conversely, its correlation with UPDRS rigidity in the m. triceps brachii was not present [30]. This disparity aligns with observations from other studies [16,33]. This finding indicates that it is the flexor muscles in the upper limb which are the muscles most affected by PD.

Myotonometry or myometry, which assesses passive muscle resistance, demonstrated ease of use and applicability across various muscles, showing a high reliability in the measurements of the targeted muscle groups. However, it is noteworthy that despite these strengths, the method showed a correlation with the UPDRSrigidity score that was not sufficiently high to be clinically acceptable [33-35].

The FIM Method is one Showing Great Promise
Particularly, this method showed both reliability and the correlation with UPDRS rigidity were excellent. This method is easily applicable in the clinic but it only exists for wrist measurements at present [37].

Another of the existing methods, AMG, also shows promise as a highly reliable and easily applicable method, demonstrating not only high accuracy but also a strong correlation with the UPDRS rigidity score. Additionally, the measured activity in the AMG method is a pressure wave originating directly from the

contracting muscle fibres creating the rigidity, thereby being a direct measurement of rigidity [16].

SEMG recordings, while providing insights into muscle activity, pose a challenge in terms of signal interpretation due to the significant influence of signals from nerves and neuromuscular junctions. This complexity limits the convenient usage of sEMG in everyday clinical settings [41]. Moreover, in terms of rigidity the sEMG signal does not measure actual muscle contraction, but rather the electrical processes that result in contractions.

Conclusion
Of the existing objective rigidity measuring techniques applied for PD, isokinetic measurements, sEMG, AMG and FIM are positively and well correlated to the UPDRS rigidity score. Myotonometry, on the other hand, does not correlate well to UPDRS rigidity. Isokinetic methods are not easily applied in the Neurology clinic, while, sEMG, FIM and AMG are. sEMG is harder to interpret due to the mixed electrical signals and is therefore not so well suited for clinical use.

In conclusion, we have identified AMG and FIM as the most promising options for objective rigidity assessment in PD. However, there is a clear need for further investigations, including a broader spectrum of PD symptoms and a larger number of subjects measured.

Conflict of Interest
None of the authors had any conflicts of interest in this study.

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